Physical and biogeochemical controls
on dissolved oxygen
in coastal upwelling systems

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cnrs dépasser les frontières

Motivation

- Global deoxygenation is a crucial issue with severe consequences to coastal ecosystems (Levin[2018],Breitburgh et al[2018])
- Eastern boundary upwelling systems are key players in global biogeochemical cycles due to their intense biological productivity and their connection with the oligotrophic open ocean.
- Climate change will bring about changes in physical and biogeochemical driving factors in EBUS.

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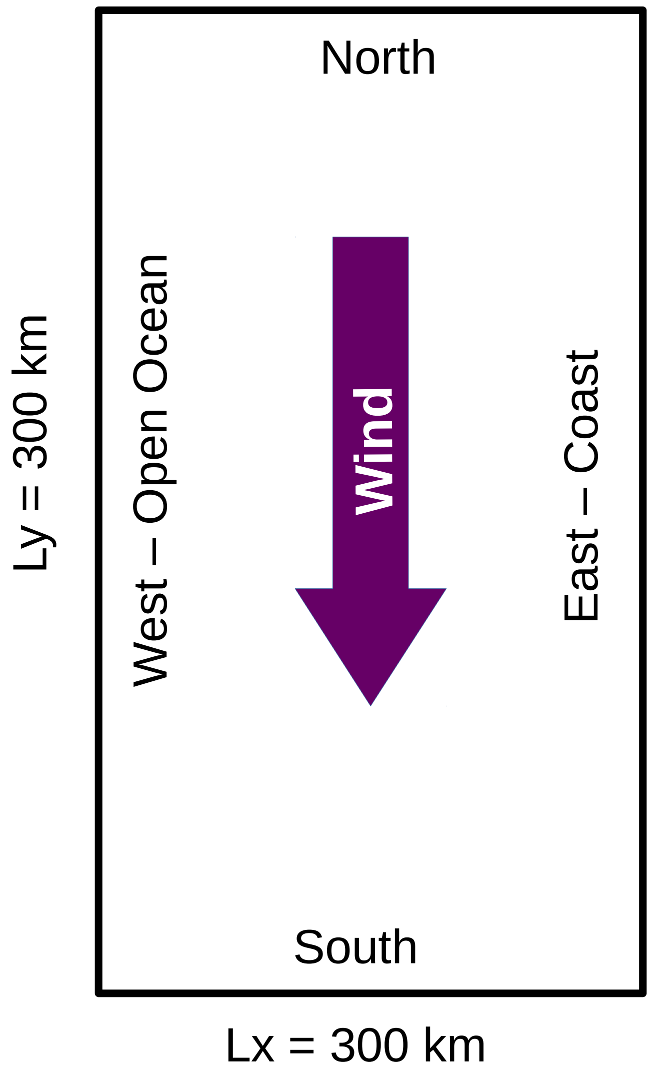
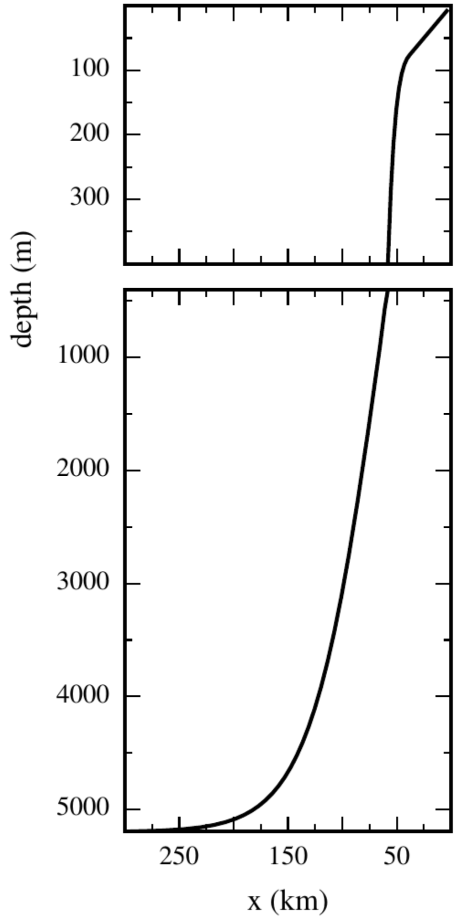
- Global deoxygenation is a crucial issue with severe consequences to coastal ecosystems (Levin[2018],Breitburgh et al[2018])
- Eastern boundary upwelling systems are key players in global biogeochemical cycles due to their intense biological productivity and their connection with the oligotrophic open ocean.
- **Climate change will bring about changes in physical and biogeochemical driving factors in EBUS. What will this mean for dissolved O_2?**

Physical model

- ROMS-CROCO hydrodynamic model
- Wind forced North-South periodic channel
- 300 km x 300 km
- 500 m x,y grid spacing
- Uniform bathymetric profile
- Initialized from rest (U=V=0)
- Temperature, Salinity initial fields from WOA2013

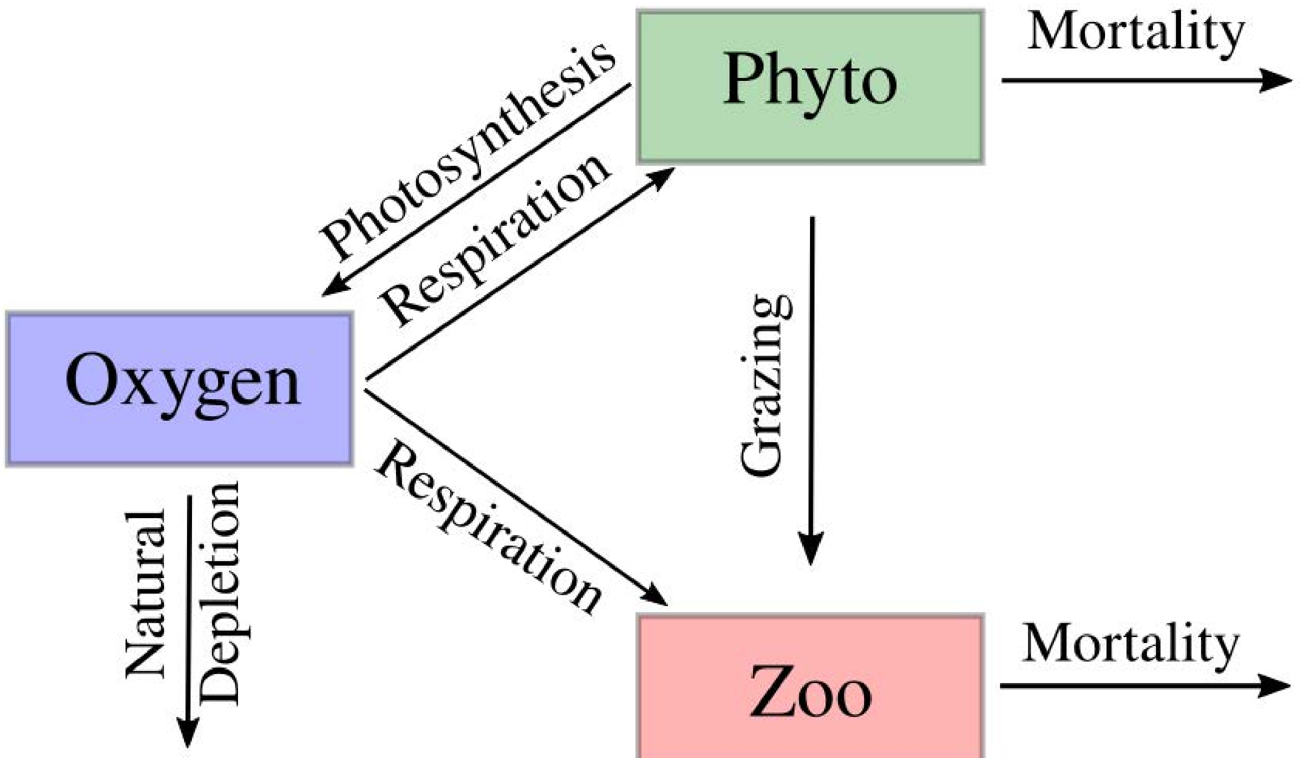


Bathymetry Profile



Biogeochemical model

- Based on *Sekerci and Petrovskii* [2015]



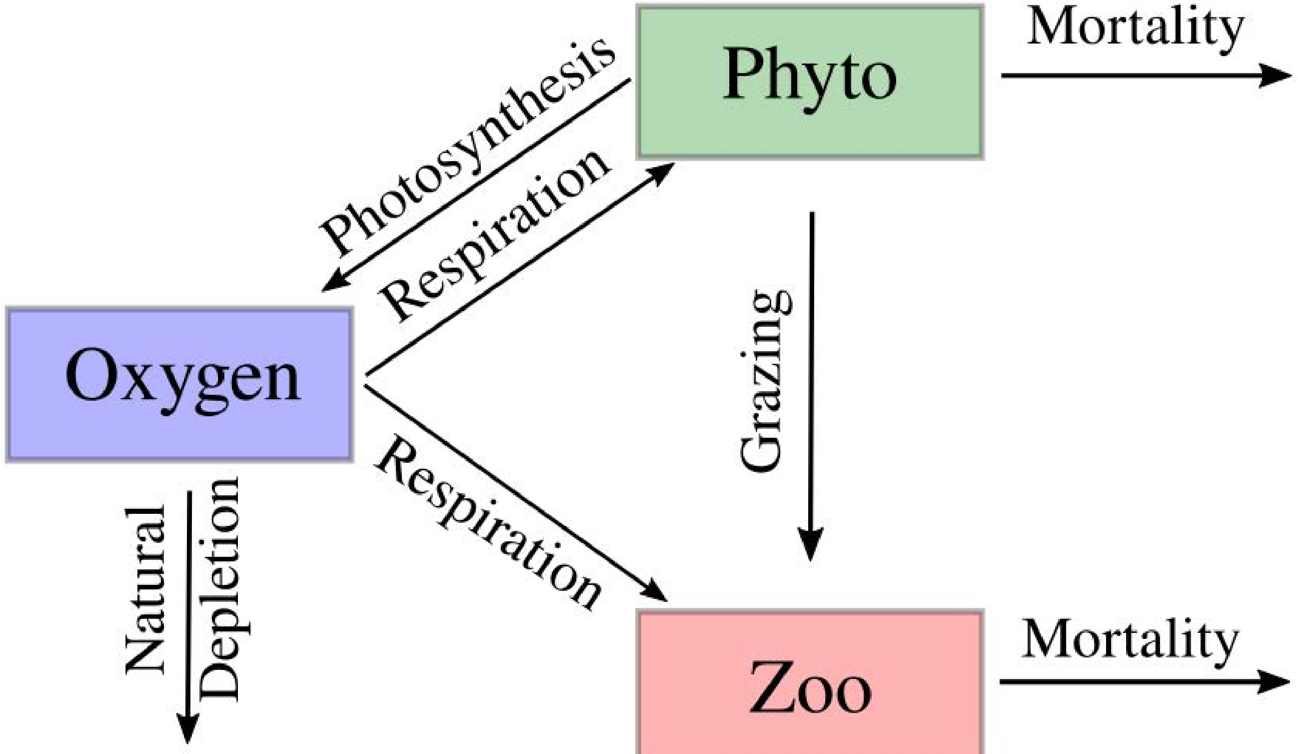
Biogeochemical model

- Based on *Sekerci and Petrovskii* [2015]
- Added nutrient input $N(\rho)$ to Phyto growth term:

$$\frac{k_1 N(\rho)}{k_2 + N(\rho)} \frac{BO_2}{c_1 + O_2}$$

k_1,B – Max growth rates

k_2,c_1 – Half-saturation constants



Simulations

Name	Phytoplankton growth	Wind
NCC	Neutral	Cyclic
LCC	Limiting	Cyclic
ECC[a]	Enhancing	Cyclic
ECS	Enhancing	Cyclic + shutdown

[a]Reference simulation.

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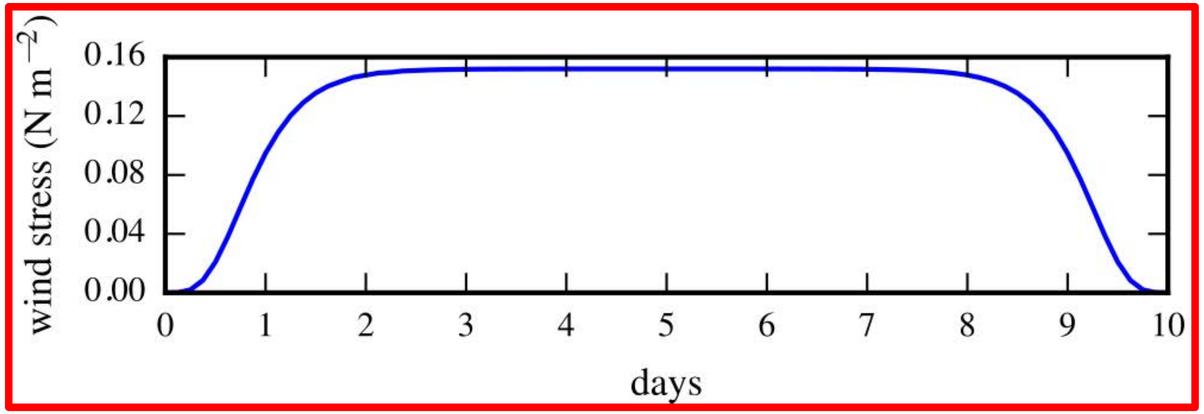
90 days (9 wind cycles)



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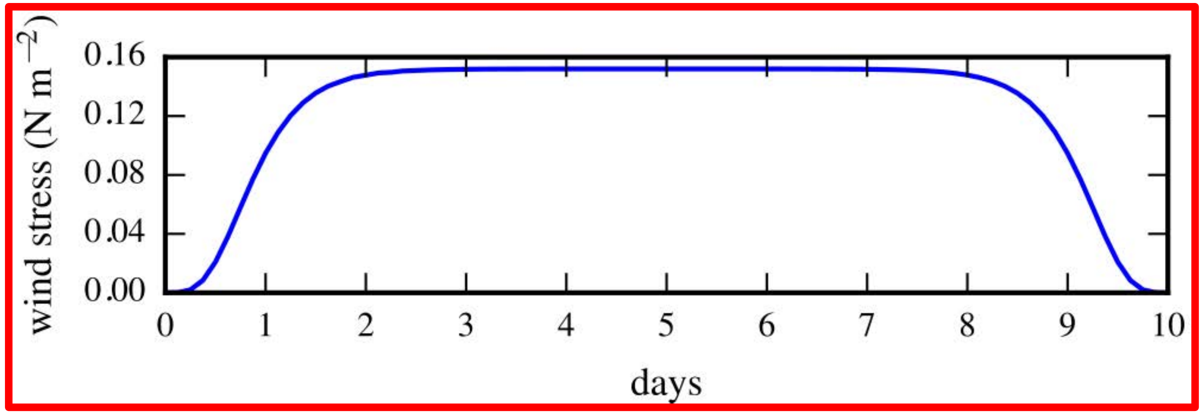
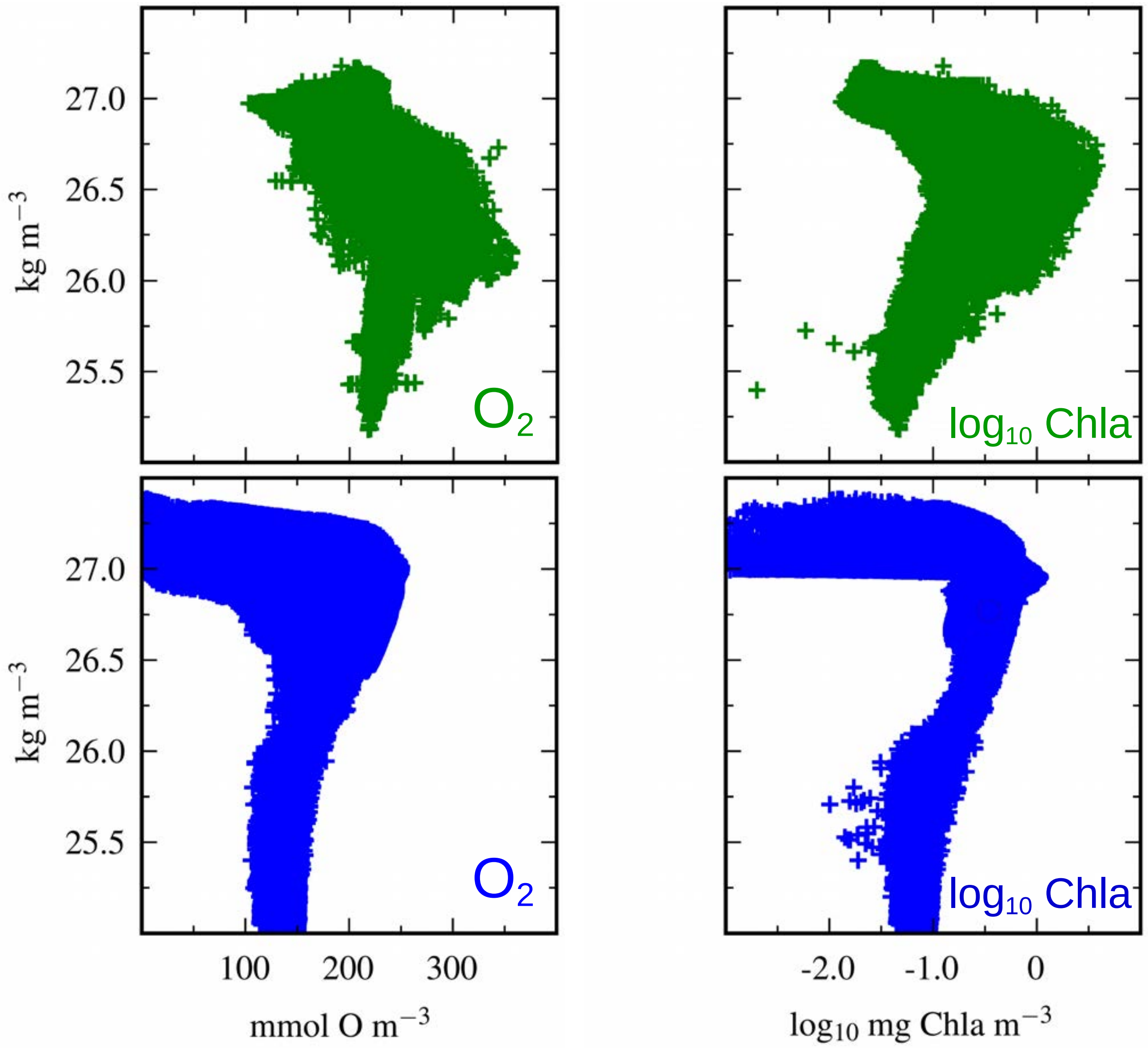
90 days (9 wind cycles)

40 days (4 wind cycles) + 50 days with no wind

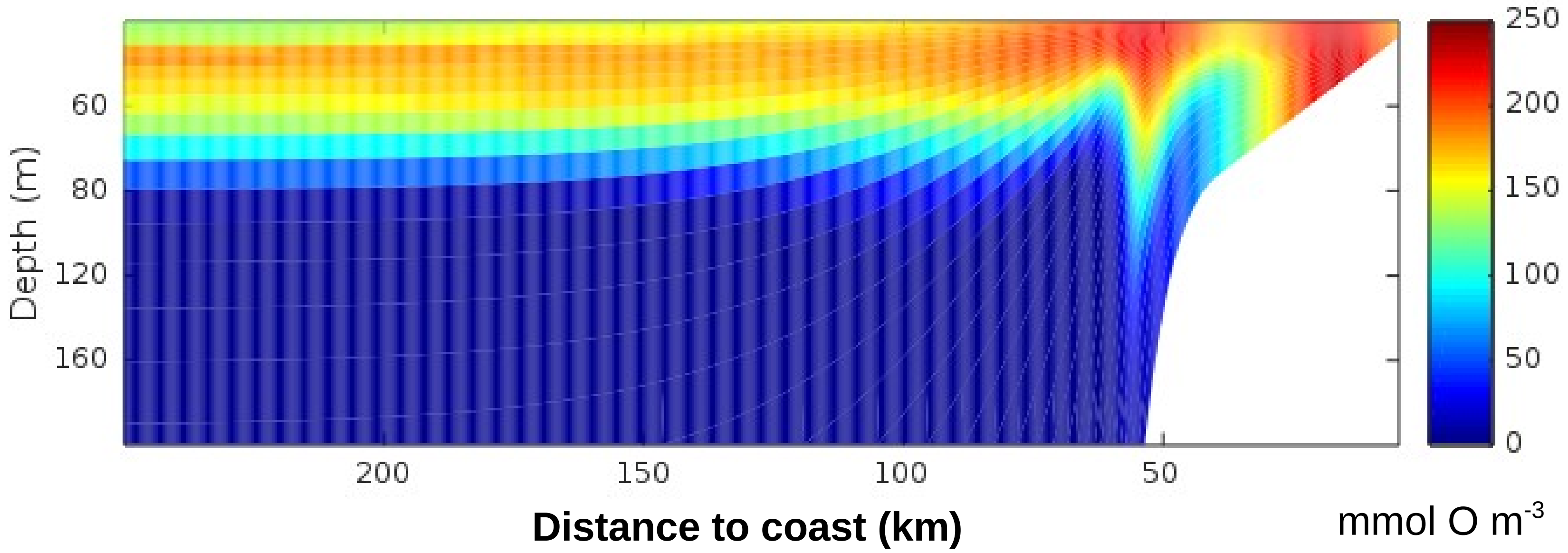


Enhanced P growth + 90 days Cyclic Wind vs. MOUTON 2007 campaign (Rossi et al[2013])



Enhanced P growth + 90 days Cyclic Wind

Time and alongshore averaged O_2



- Offshore gradient of surface O_2 as upwelling induced P growth and O_2 production

Enhanced P growth + 90 days Cyclic Wind

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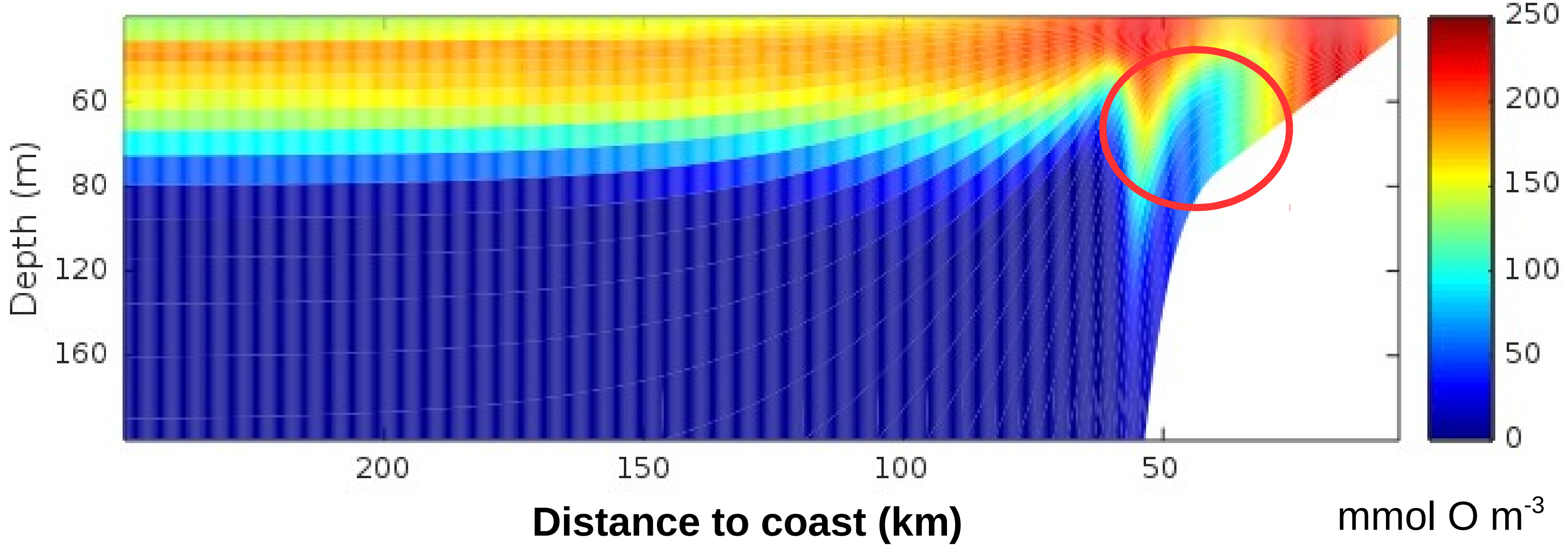
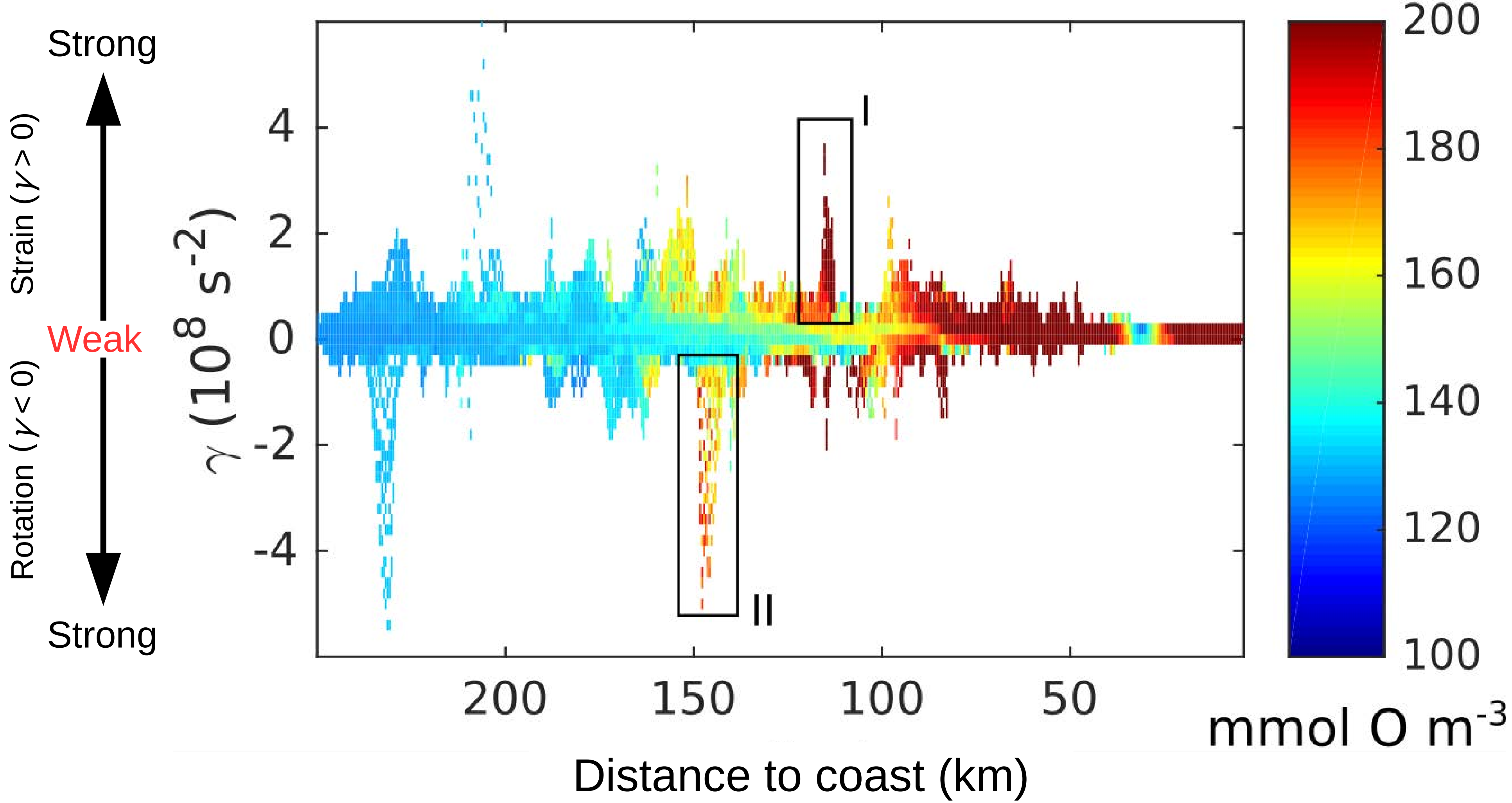


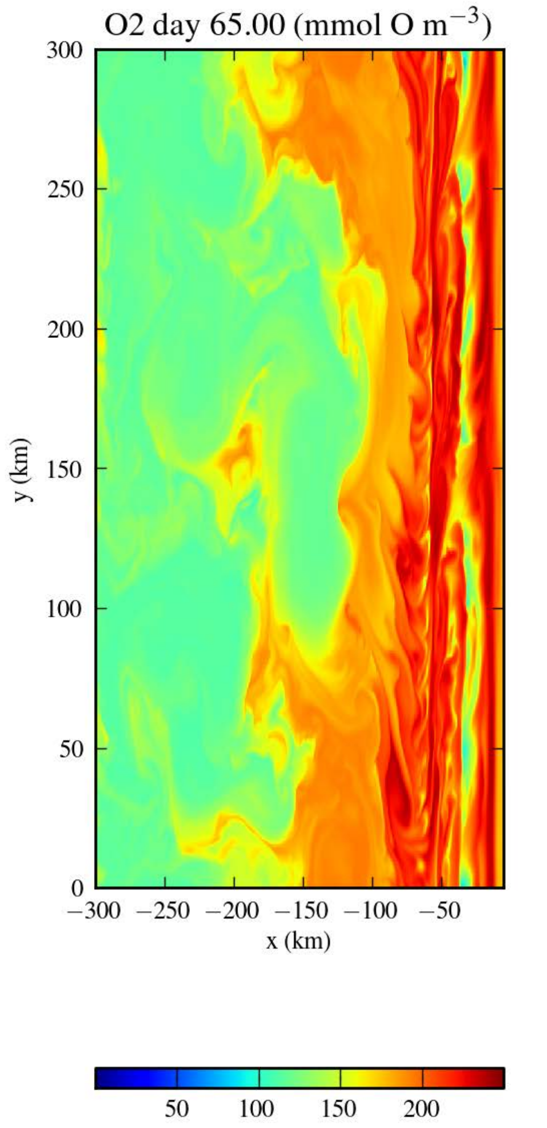
- Offshore gradient of surface O_2 as upwelling induced P growth and O_2 production
- Subsurface low O_2 pocket appears as O_2 poor waters are upwelled

Turbulent O_2 structure

Surface O_2 by Okubo-Weiss (γ) and offshore position Day 65



Enhanced P growth + 90 days Cyclic Wind



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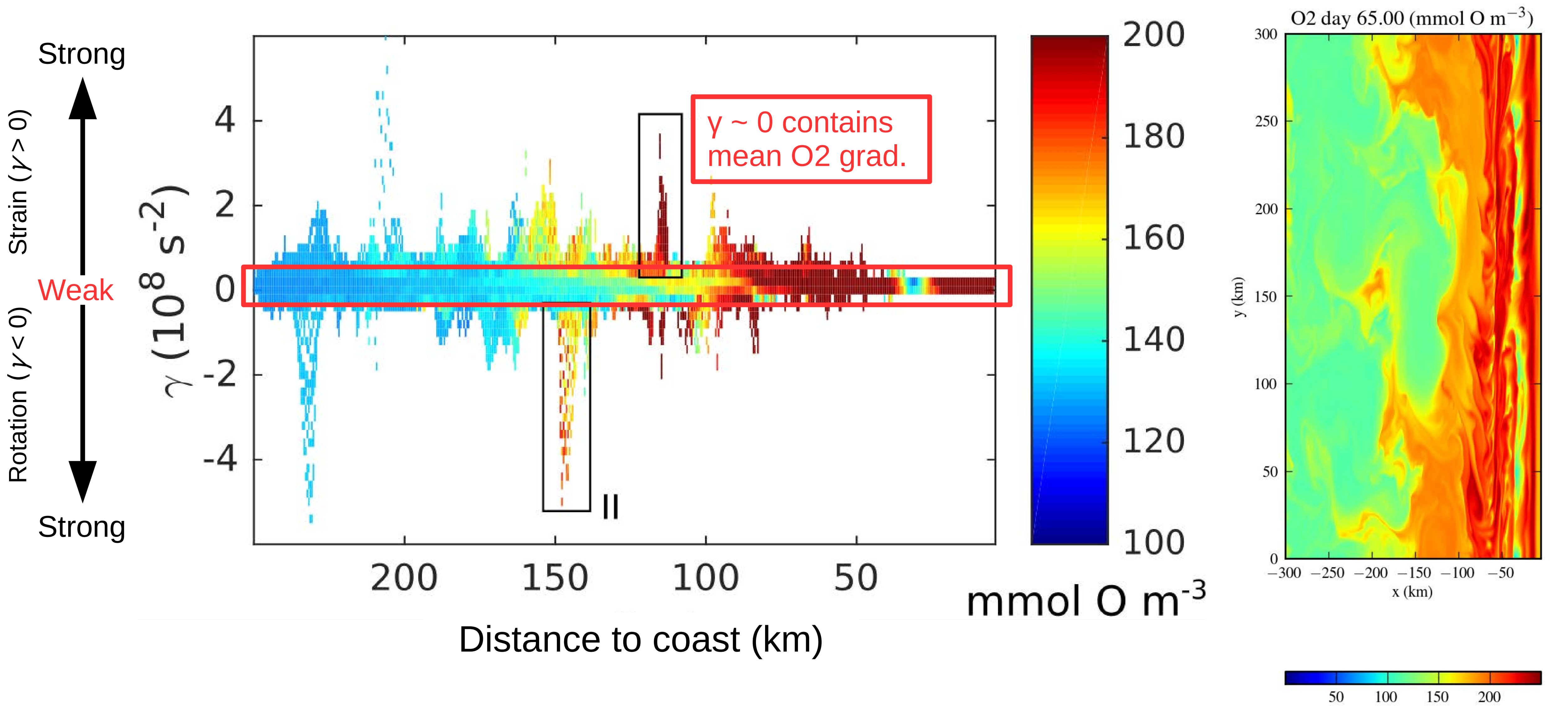

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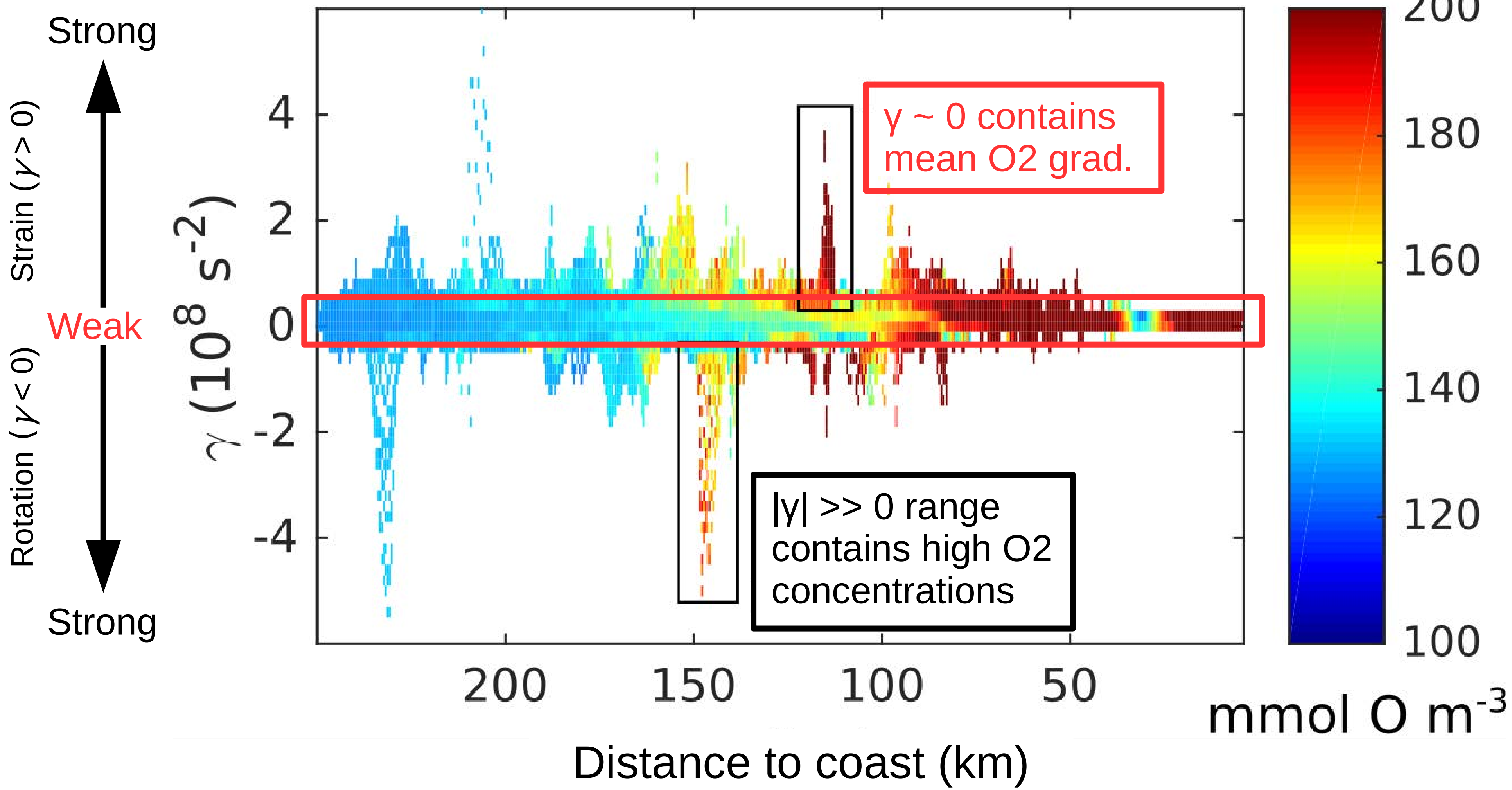
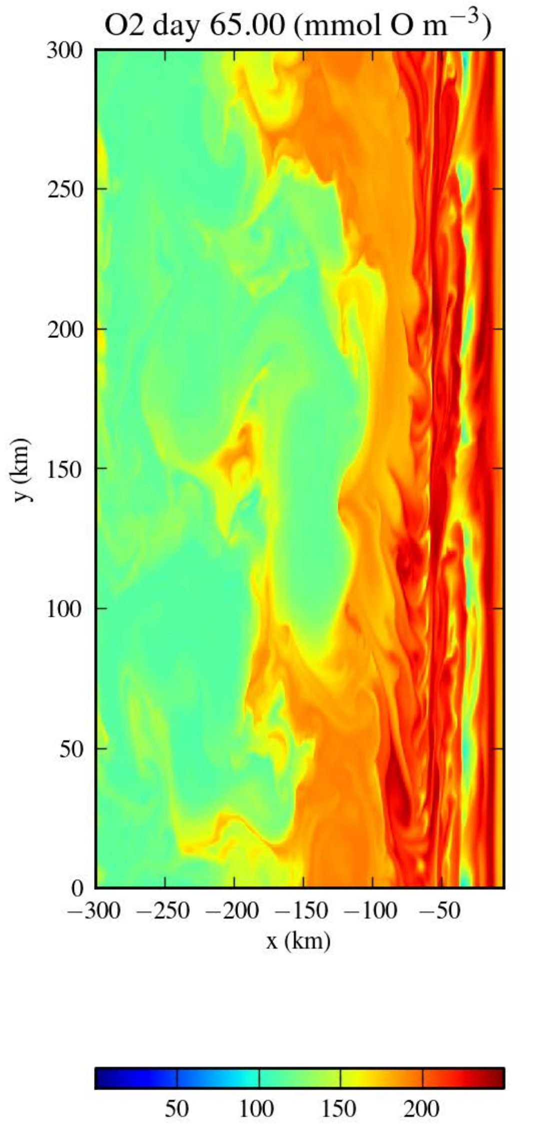
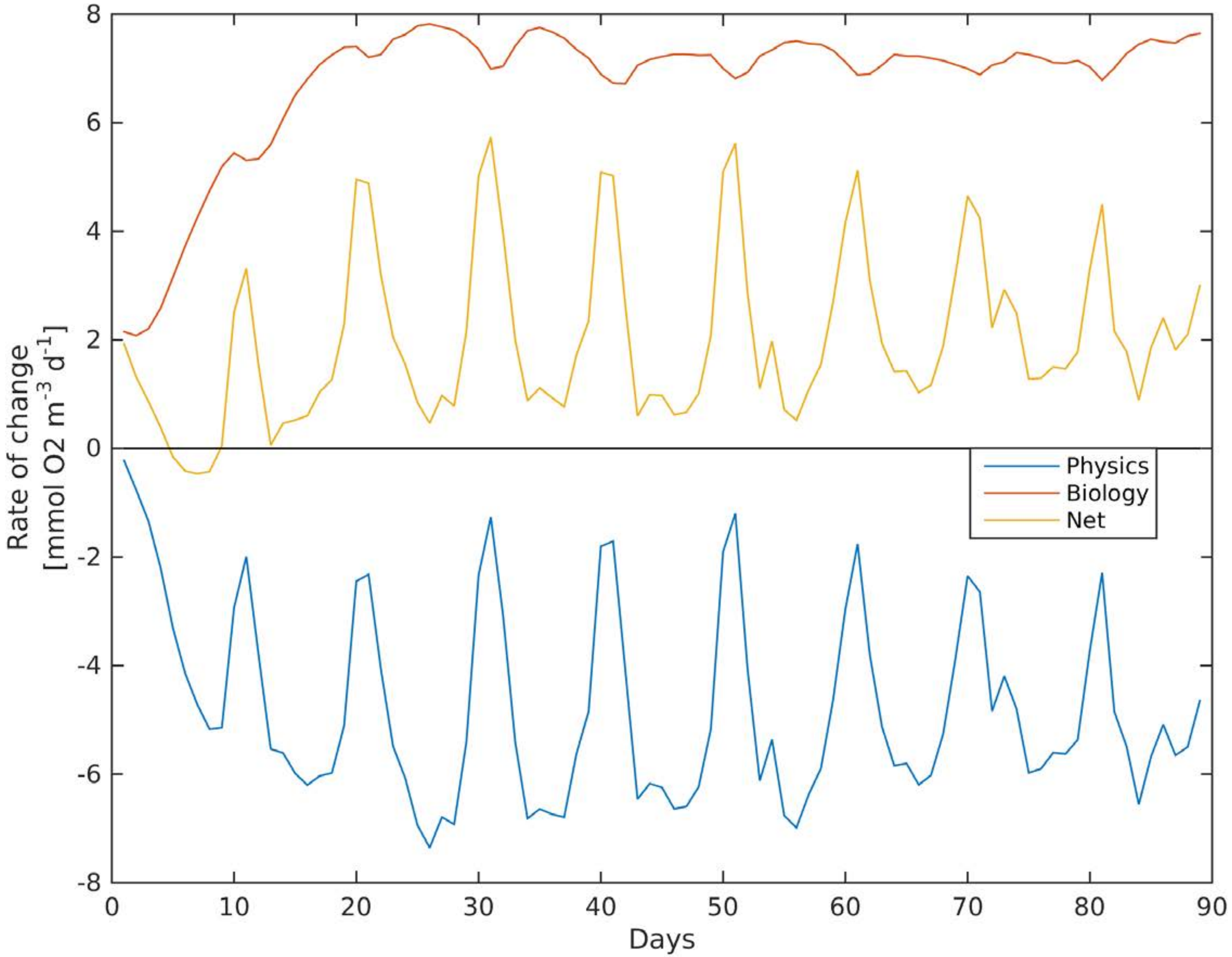




Coastal O_2 budget

(0<x<50 km, z < 140 m)

Enhanced P growth + 90 days Cyclic Wind



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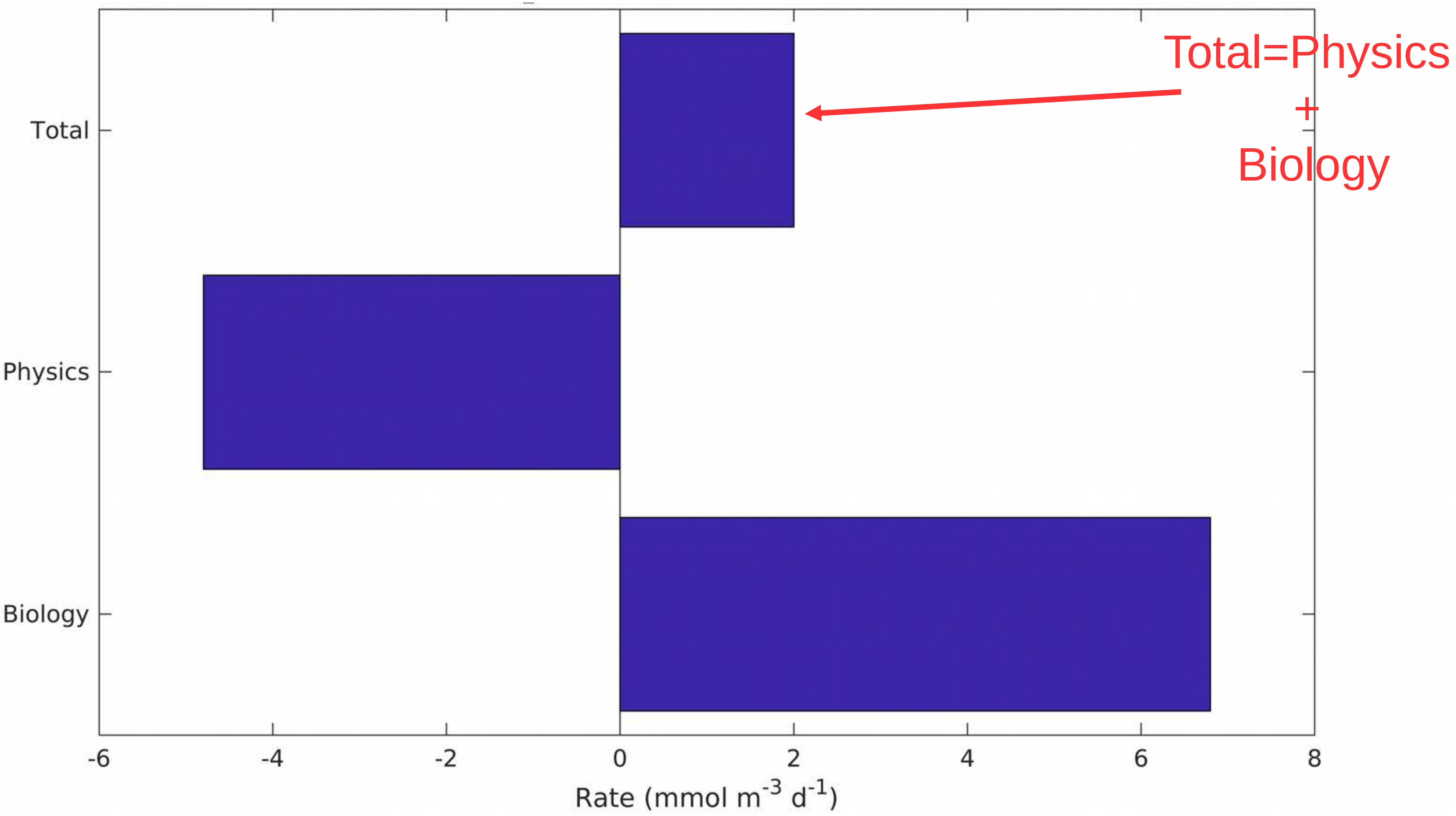

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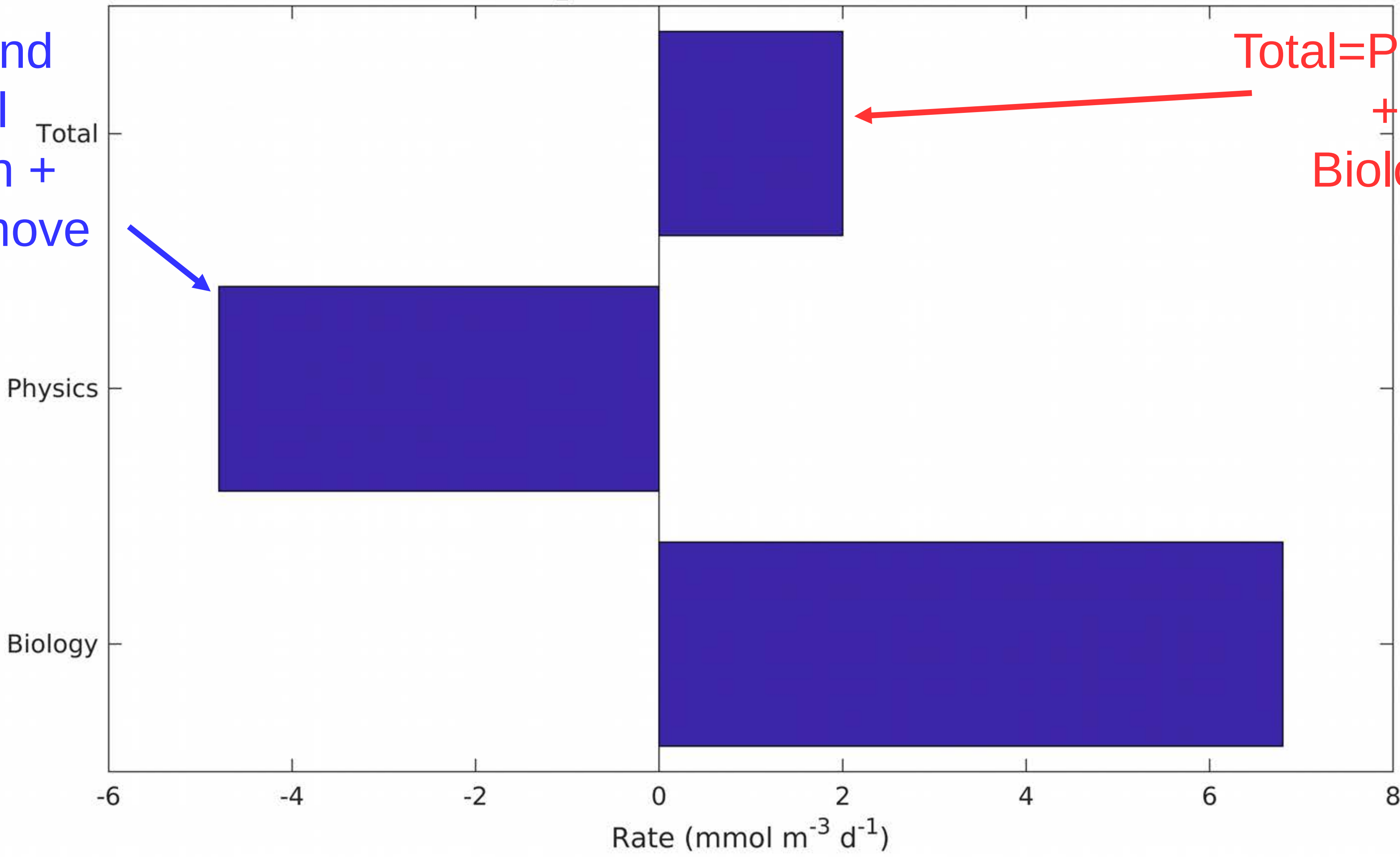
Enhanced P growth + 90 days Cyclic Wind

Lateral and vertical advection + mixing remove O_2



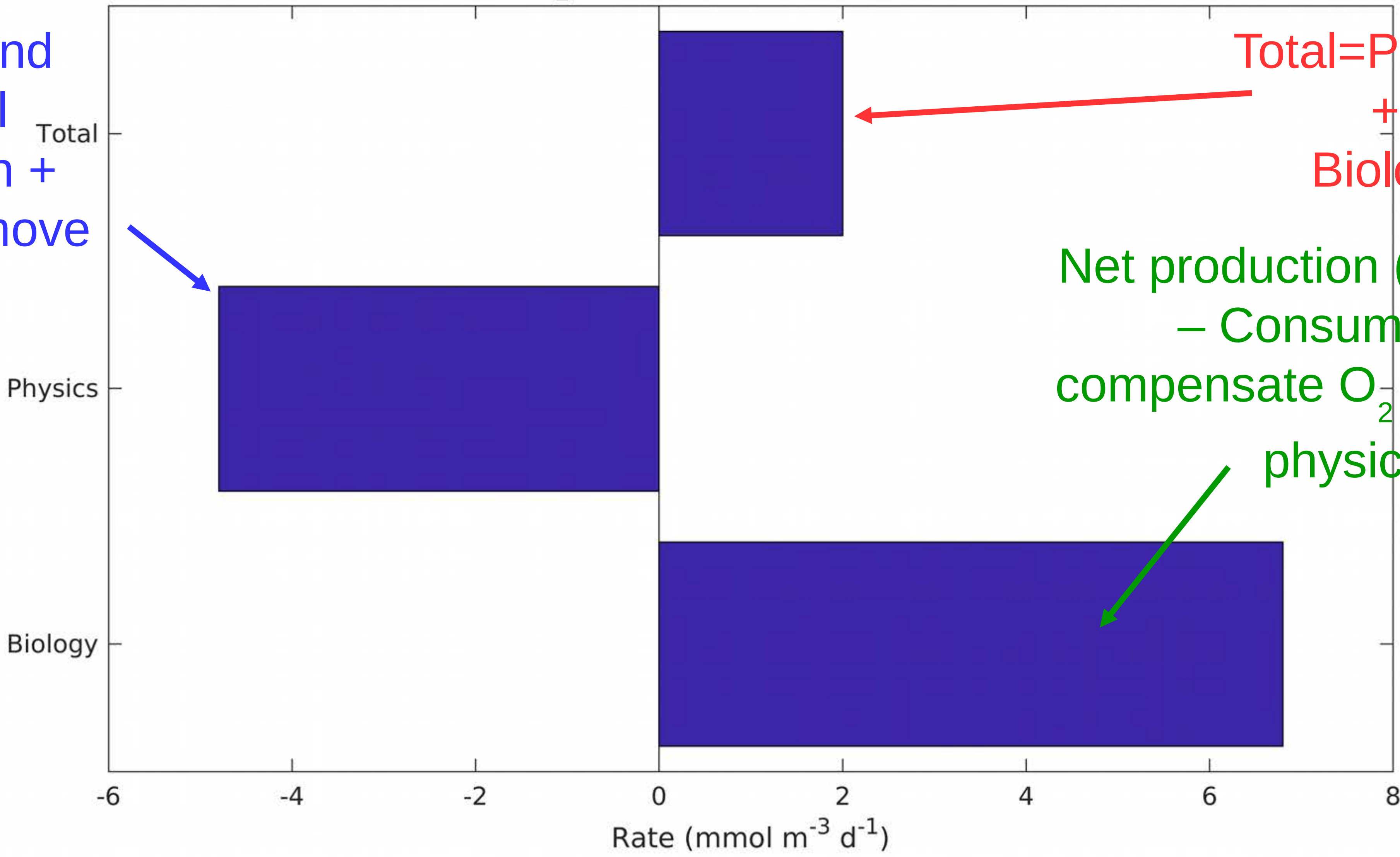
Total=Physics + Biology

Coastal O_2 budget

(0<x<50 km, z < 140 m)

Enhanced P growth + 90 days Cyclic Wind

Lateral and vertical advection + mixing remove O_2



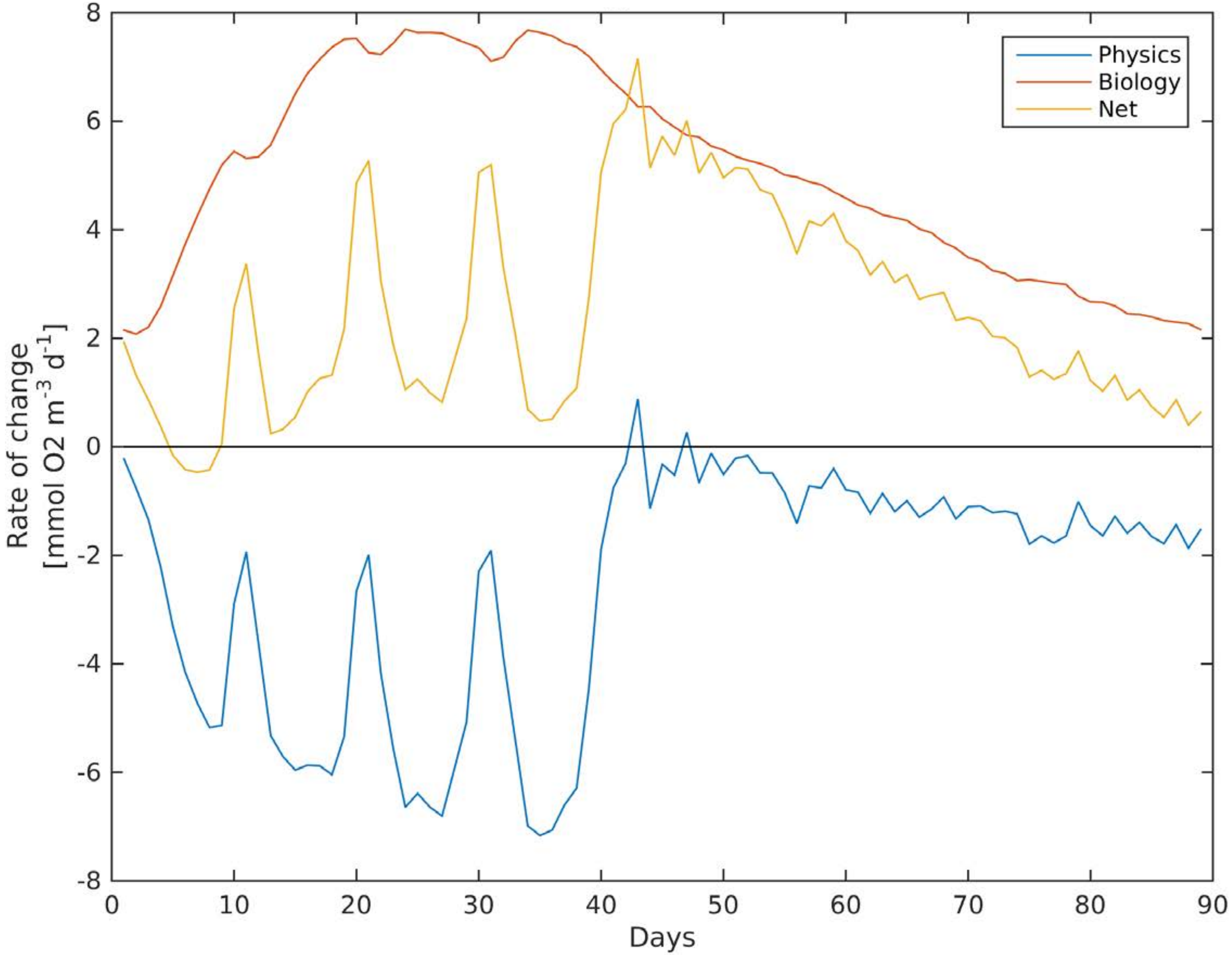
Total=Physics + Biology

Net production (Production – Consumption) compensate O_2 removal by physics

Coastal O_2 budget

(0<x<50 km, z < 140 m)

Enhanced P growth + Wind shutdown



Coastal O_2 budget

Enhanced P growth

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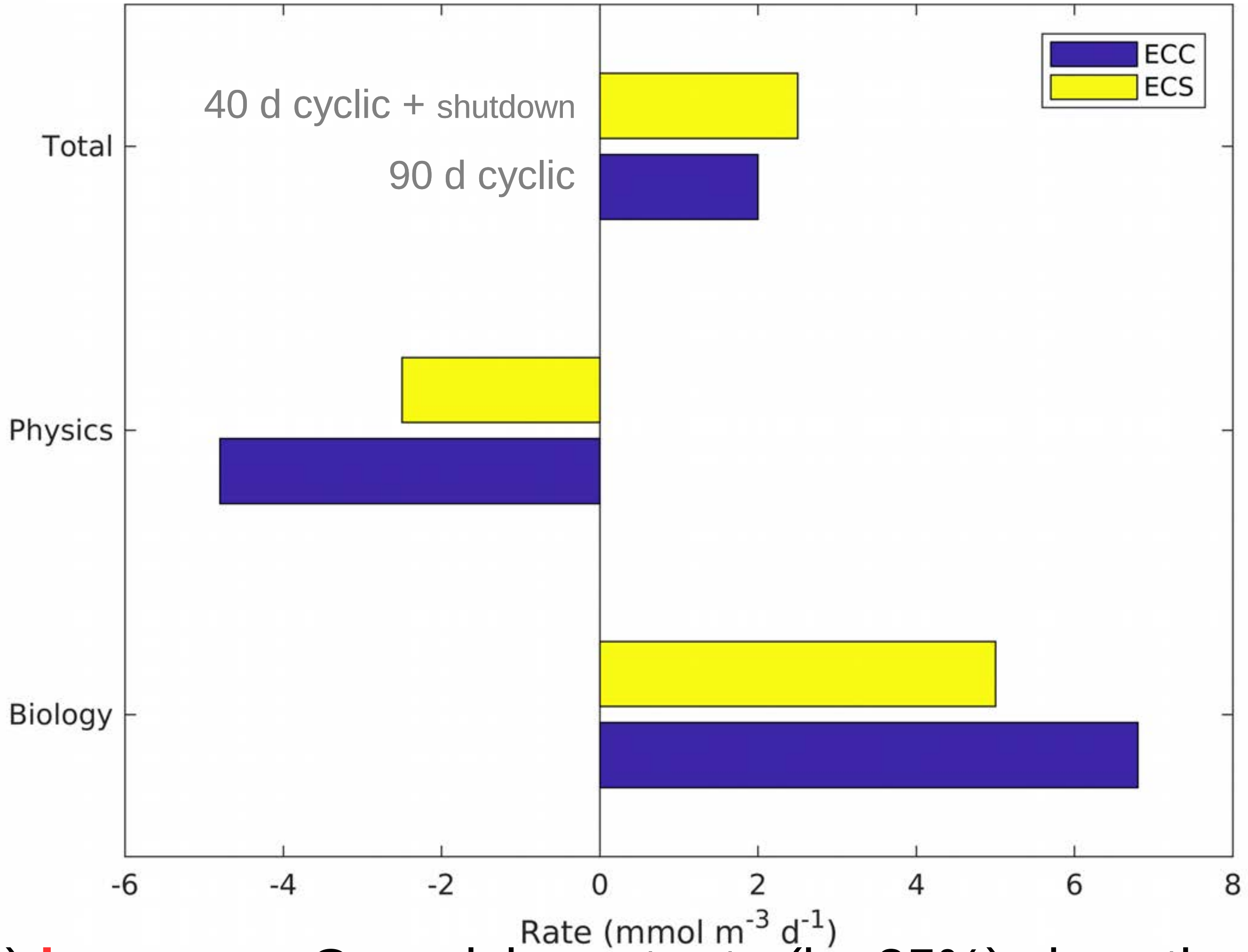
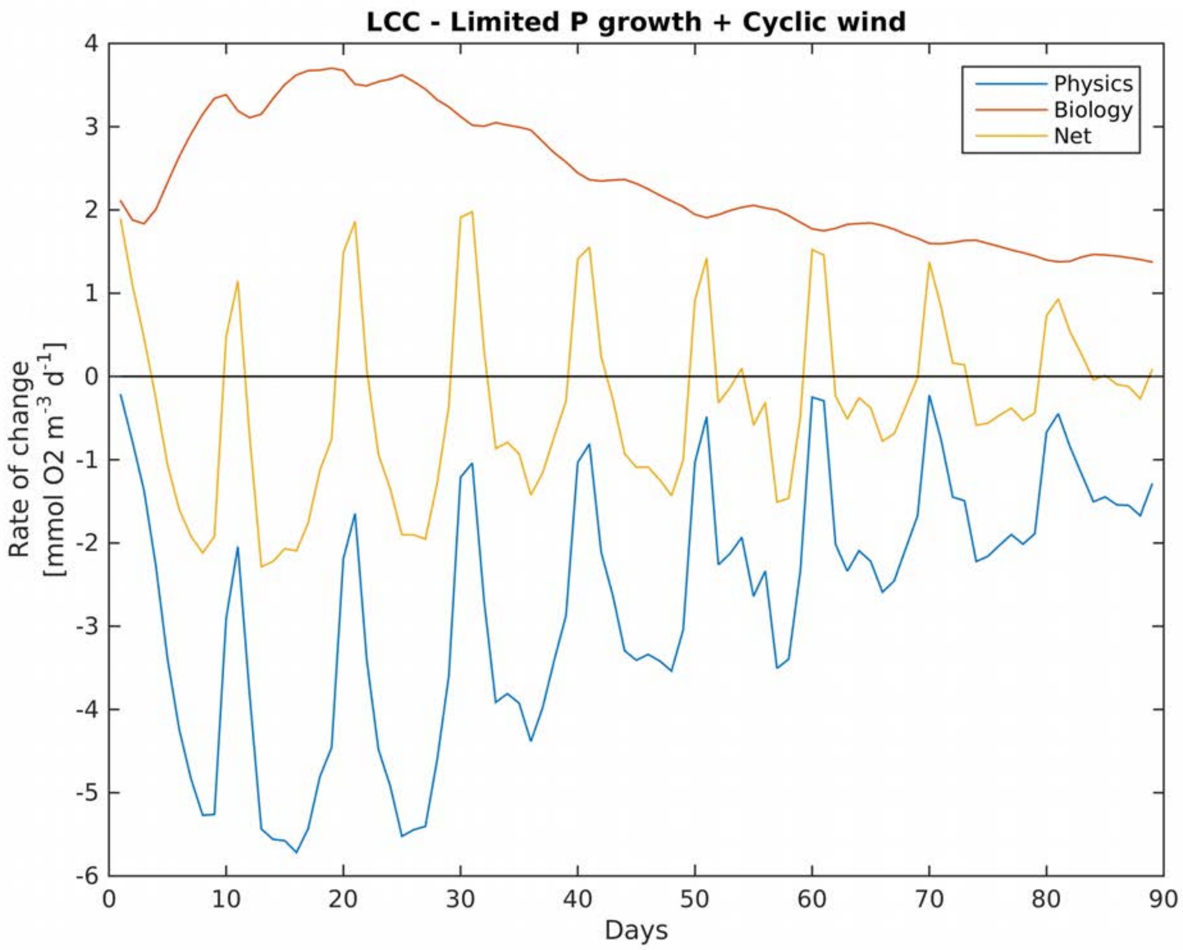


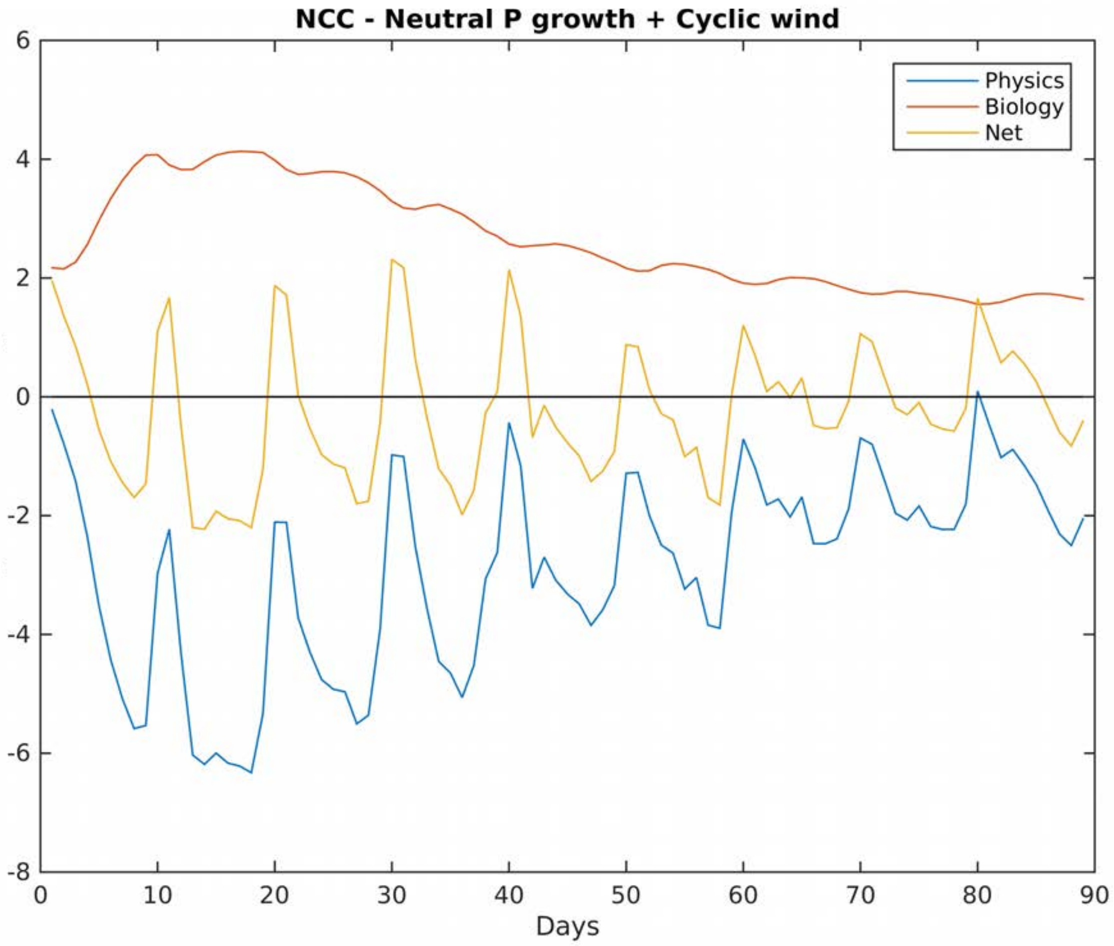
Wind shutdown (ECS) **increases** O_2 enrichment rate (by 25%) since the decline in advective sink is larger than the decline in net production

Coastal O_2 budget

90 day cyclic wind

(0<x<50 km, z < 140 m)





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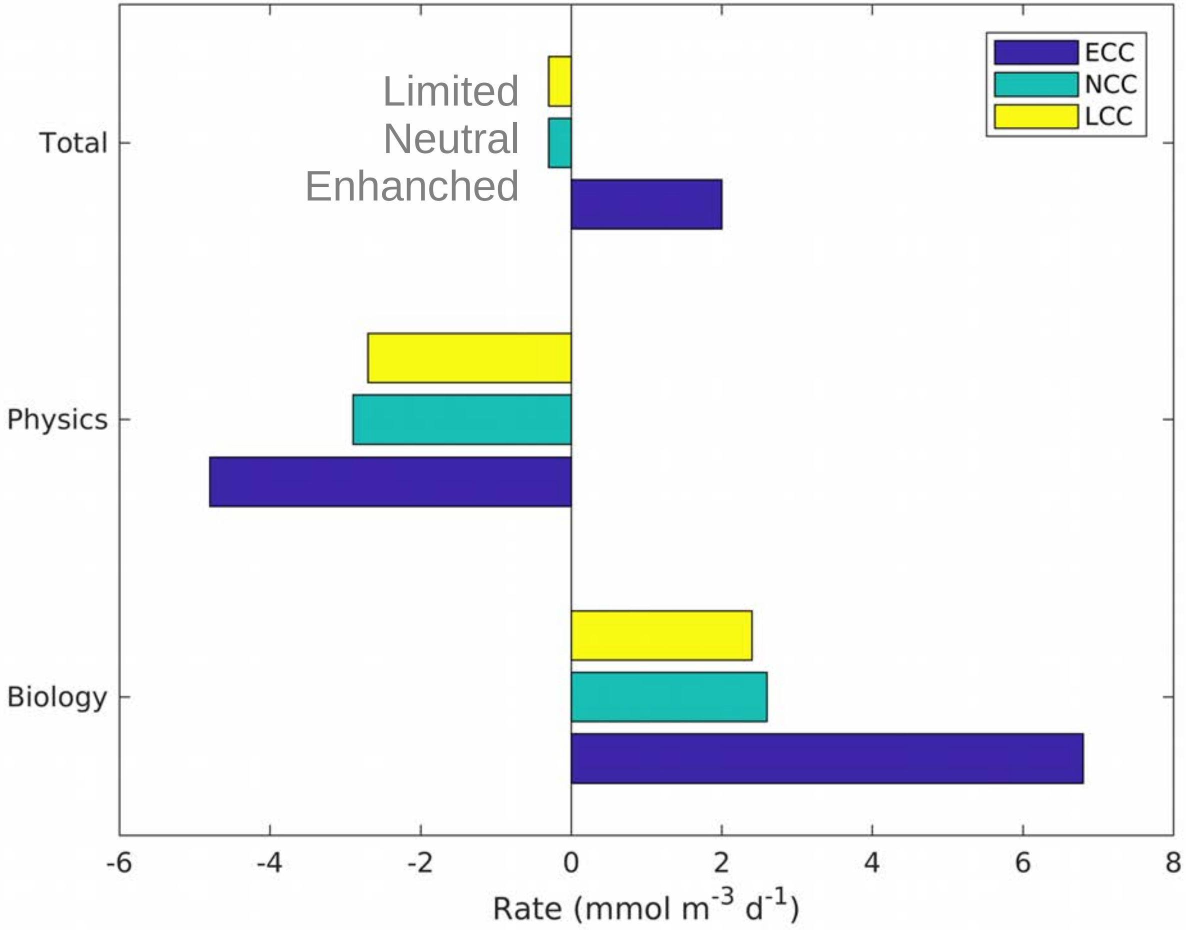

Decrease in P growth causes mean loss of O_2 in coastal box

Net production rates fall but remain positive.
Physical sink also decreases but less than biological source

Conclusions

- We used an idealized coupled physical-biogeochemical model to study dissolved O_2 in coastal upwelling systems
- **Lateral transport by turbulence moves O_2 rich waters offshore**
- **Upwelling shutdown increases O_2 enrichement in the coastal zone**
- **Phytoplankton growth limitation causes O_2 loss in the coastal zone**
- Future work will look at including wind drop off and current feedbacks to the atmosphere

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O2PZ Model equations

The model equations for the concentrations of the biogeochemical tracers are:

$$\frac{d[\mathrm{O_2}]}{dt} = Af\left([\mathrm{O_2}]\right)[\mathrm{P}] - u_r\left([\mathrm{O_2}],[\mathrm{P}]\right) - v_r\left([\mathrm{O_2}],[\mathrm{Z}]\right) - m \cdot [\mathrm{O_2}], \tag{1}$$

$$\frac{d[\mathrm{P}]}{dt} = g\left([\mathrm{O_2}],[\mathrm{P}]\right) - e\left([\mathrm{P}],[\mathrm{Z}]\right) - \sigma \cdot [\mathrm{P}], \tag{2}$$

$$\frac{d[\mathrm{Z}]}{dt} = \kappa\left([\mathrm{O_2}]\right) e\left([\mathrm{P}],[\mathrm{Z}]\right) - \mu \cdot [\mathrm{Z}]. \tag{3}$$

O2PZ Model Parameters

Table 1. Parameters of the O_2PZ model.

Parameter	Value	Units	Description
A	540.0	d^{-1}	Environmental effects in rate of O_2 production inside phytoplankton cells.
c_0	255.3	mmol O m^{-3}	Half-saturation constant for O_2 production.
δ	200.0	d^{-1}	Maximum per capita phytoplankton respiration rate.
c_2	255.3	mmol O m^{-3}	Half-saturation constant for O_2 respiration by phytoplankton.
ν	350.0	d^{-1}	Maximum per capita zooplankton respiration rate.
c_3	255.3	mmol O m^{-3}	Half-saturation constant for O_2 respiration by zooplankton.
m	0.03	d^{-1}	Rate of oxygen loss due to natural depletion.
B	0.055	d^{-1}	Maximum per capita phytoplankton growth rate.
c_1	17.02	mmol O m^{-3}	Half-saturation constant for phytoplankton growth.
γ	0.1	$mmol^{-1}$ O m^3 d^{-1}	Intensity of intra-specific competition.
β	0.9	d^{-1}	Maximum zooplankton predation rate.
h	0.8	mmol N m^{-3}	Half-saturation constant for phytoplankton predation.
σ	0.027	d^{-1}	Phytoplankton mortality rate.
η	0.75	–	Maximum zooplankton feeding efficiency.
c_4	255.3	mmol O m^{-3}	Half-saturation constant for zooplankton feeding efficiency.
μ	0.025	d^{-1}	Zooplankton mortality rate.

Nitrate vs Density

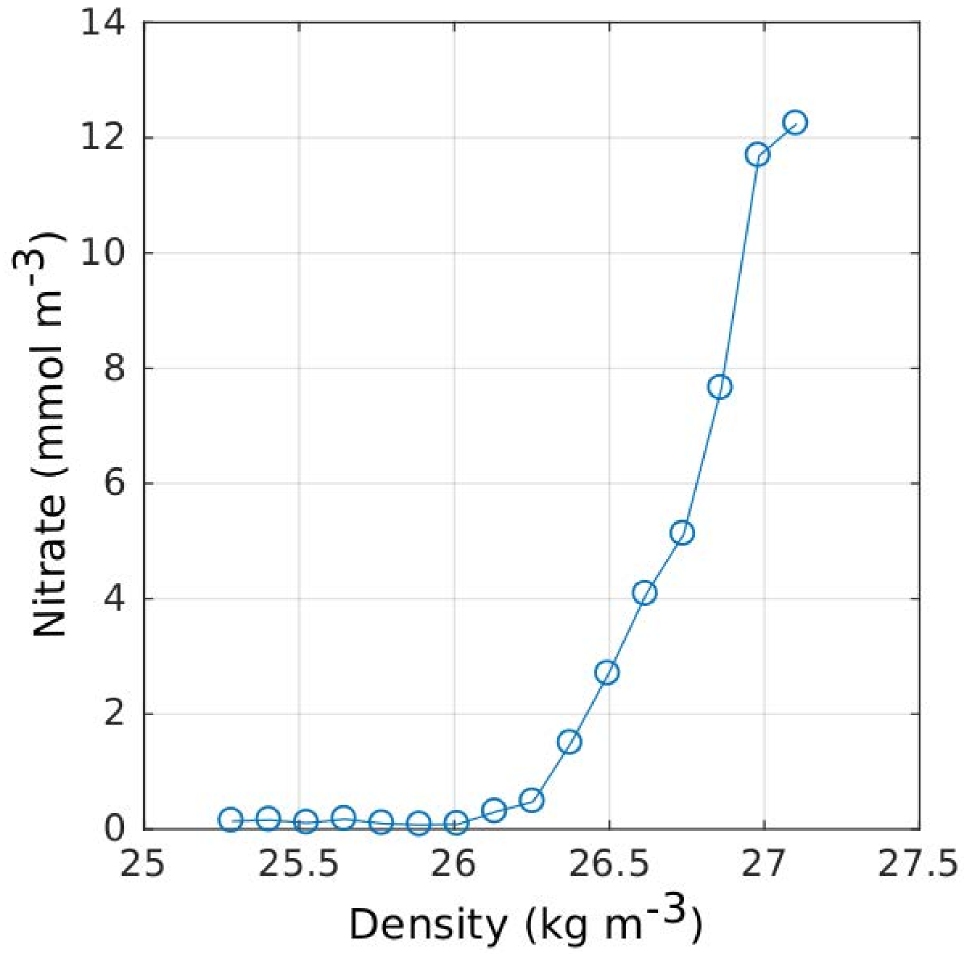


Figure 1. Nitrate–density curve from measured data in the MOUTON cruise

O2 Lateral Fluxes

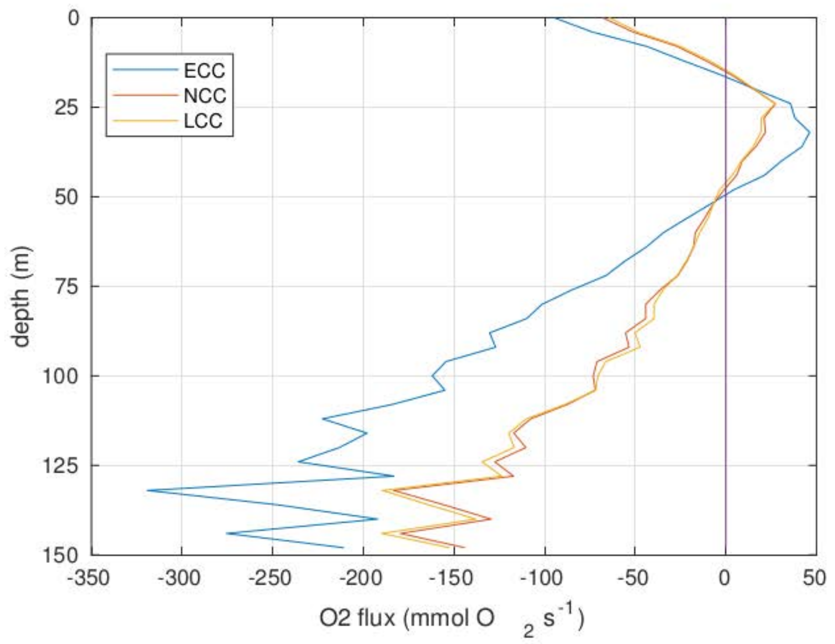
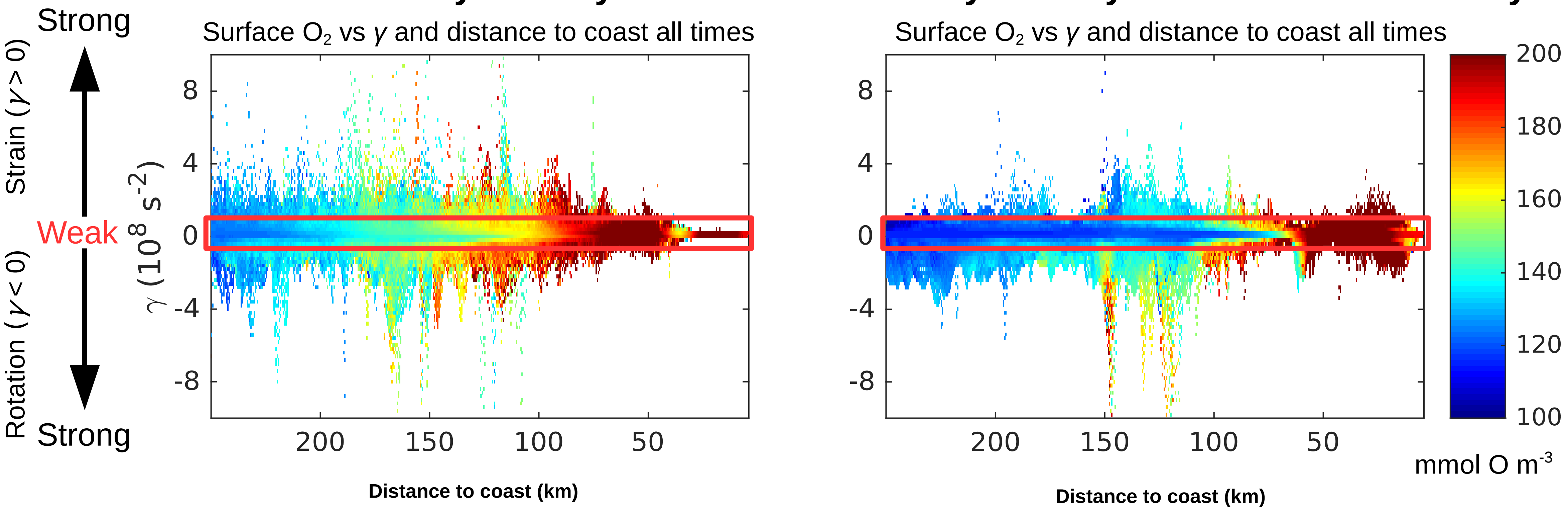


Figure 3. Vertical profile of x advection dissolved O_2 flux. The x advection flux is given by $u\ \frac{\partial[O_2]}{\partial x}\ V$, where u is the cross-shore velocity and V is the volume. The flux is averaged in the alongshore direction, then time averaged between days 20 and 90 and then it is averaged in the cross-shore direction in the $0<x<50$ km region. ECC - Enhanced P growth and cyclic wind for 90 days; NCC - Neutral P growth and cyclic wind for 90 days; LCC - Limited P growth and cyclic wind for 90 days.

Enhanced Phytoplankton Growth

Sensitivity to Wind Regime

9 x 10 day wind cycle | **4 x 10 day wind cycle + no wind for 50 days**



The O_2 offshore gradient is intensified when the wind shuts downs as turbulence winds down and O_2 offshore transport is slowed down